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Article

Scale of production and technical efficiency of beef cattle farming in Puebla, Mexico

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Abstract:

The objective of this study was to estimate the degree of technical efficiency and identify the factors of inefficiency of beef cattle production in the Sierra Norte of Puebla, Mexico. The data were generated by surveying a statistical sample of 180 bovine production units (BPUs). Technical efficiency was estimated using the Stochastic Production Frontier and the explanation of inefficiency was estimated with a multiple linear regression model. The results indicate that the size of the BPU is positively correlated with efficiency; the small BPU group showed an average efficiency of 0.72, the medium ones 0.75 and the large ones 0.85. Feed and labor costs can be reduced, while maintaining the same level of production. The significant ($P \leq 0.05$) explanatory variables of inefficiency are schooling, technical assistance, experience, and administrative management.

Key words: Cattle, Technical efficiency, Production scale, Production frontier.

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Introduction

According to official data[1], in 2017 Mexico produced 3.5 million tons of live cattle and 1.9 million tonnes of beef. National consumption for 2019 was 1.83 million tonnes. National production, in the last 15 yr, shows a mean growth rate (MGR) of 1.6 %, while demand grew at a MGR of 0.21, reflecting a fall in consumption, explained by the increase in prices[2]. In this regard, per capita consumption went from 18 kg in 2007 to 15.1 in 2017. However, in 2017 imports totaled 136 thousand tonnes[3].

In Mexico, non-specialized beef production presents difficulties in being profitable, especially that carried out by small and medium-sized bovine production units (BPUs), which obtain negative or very low rates of return[4]. This type of BPU was one million in 2018. According to the 2014 National Agricultural Survey [5], 62 % of the BPUs have 1 to 10 heads, 26 % from 11 to 35, 9.9 % from 36 to 120, and 1.6 % more than 120 heads. Therefore, approximately 88 % of BPUs are small. Given the importance of this sector and of cattle to generate family income, it is necessary to support their development through the analysis of the technical-economic factors that have a greater impact on their productivity[6].

A factor that negatively affects the economic profitability of small farmers is the low productivity and technical efficiency at the level of BPU[7]. Another important factor is the growth rate of inputs, which is higher than that of the price of the output[8]. Therefore, the challenges posed by the problems described can be addressed through the improvement of the productive efficiency of BPUs. Productive efficiency can improve the profitability of BPUs through lower costs and greater supply to the market.

Productive efficiency[9] is defined as the situation in which a cattle production unit (CPU) that produces a single product can improve its production only if it increases the use of at least one of its inputs. The literature on efficiency focuses on two aspects; measurement of technical and economic efficiency and sources of inefficiency. Efficiency studies have been carried out in a wide variety of agricultural production activities; grains[10]; vegetables[11], dairy[12], and coffee[13]. In the world, few studies have addressed efficiency in beef cattle[14,15,16]. In these it was found that there are significant deviations from the efficient production frontier.

In Mexico, Morales-Hernández *et al*[17] conducted the only available study of beef production efficiency in Mexico. They found that for small producers, as factors of production increase by a certain proportion, production grows less than proportionally. On the other hand, for the large ones, as the factors increased by a certain proportion, production grew in greater proportion. It is not necessary to increase the amount of feed or the area of pasture to increase the total amount of beef, but the number of animals.

The study of the efficiency of BPUs and the sources of inefficiency are therefore important from a practical and political point of view. On the one hand, farmers could use this information to improve the productivity of their farm. On the other hand, policymakers could focus interventions to improve producer income[18].

The objective of this study was to address this gap in knowledge by estimating the degree of efficiency, and to identify the factors of inefficiency of beef cattle production in the Sierra Norte of Puebla, Mexico, from an econometric perspective.

Material and methods

For the present study, seven municipalities of the Sierra Norte of Puebla were selected (Table 1). The study area was located at coordinates 19° 59' 10" and 20° 34' 20" N; 97° 19' 97" and 97° 47' 98" W. The altitude ranged from 10 to 1,700 m asl. The climate is warm humid with abundant rainfall all year round, except the municipality of Xicotepec, which has a humid semi-warm climate. The vegetation is composed of pasture (35 %), jungle (13 %) and forest (6 %)[19]. These municipalities contribute 32.1 % of cattle production at the state level[3].

The methodology consisted of four stages: the first was the knowledge of the region, where the survey of the area was carried out, and interviews were conducted with leading producers and technicians to know general aspects of cattle farming; the second was the design of the sampling, of a simple random type, with proportional distribution, according to the number of producers in each municipality. The population used corresponds to 60,020 BPUs, reliability was 95 % and accuracy was 7.5 % of the herd size mean, resulting in a sample size of 180 BPUs. The third stage consisted of the design, testing and application of questionnaires, distributed proportionally in the municipalities of the study (Table 1). The fourth stage was the statistical analysis of the data derived from the questionnaire, which were organized into sociodemographic, technological, and economic variables.

Table 1: Distribution of the sample size

Municipality	Population (N)	Participation (%)	Sample (n)
Francisco Z. Mena	6791	11.31	54
Venustiano Carranza	11898	19.82	36
Tenampulco	3909	6.51	27
Pantepec	17919	29.86	20
Xicotepec	4734	7.89	18
Jalpan	8860	14.76	14
Ayotoxco de Guerrero	5909	9.85	12
Total	60020	100	180

The economic characterization of the cattle production units with the aforementioned variables is very useful for producers, since it allows them to know the behavior of their company and they can make decisions in their activities to minimize costs, improve productivity and profitability of the company. Therefore, it is important to distinguish between accounting costs and economic costs.

The cost accounting perspective emphasizes expenditures incurred, historical costs and depreciation. Economic costs represent the opportunity cost of the factors of production. One way to differentiate between these two approaches is to analyze how the costs of various factors (labor, capital, or business services) and the accounting or monetary costs, which are the costs incurred by the production unit for the purchase of inputs and assets at market prices(20), are defined.

For the purposes of this research, the total costs (TC) are the result of the sum of fixed costs (FC) and variables costs (VC) (TC = FC + VC). Fixed costs are those charges assumed by the production unit regardless of its level of production, including the option of zero productions. Variable costs are those that change depending on the level of production of the LPU. Total costs include: the cost of total labor, based on the sum of eventual labor (brush clearing and fertilizer application), and permanent labor (commonly known as payment for the cowboy and the *flotante*), which they require annually for cattle handling; cost of inputs (feed, medicines and others); and the cost of machinery and equipment (including depreciation rate of each asset, considering a value of 10 % per year).

The basis for defining the strata of herd size was the segmentation of livestock units of SAGARPA(21), which considers a stratum A made up of 20 heads or less, stratum B from 21 to 50 heads, and stratum C made up of a herd greater than 50 heads. The above to serve the CPUs in a differentiated way. Once the groups were formed, the following were carried out: econometric analysis; estimation of the stochastic production frontier and estimation of an explanatory model of inefficiency.

Stochastic frontier model

The assumption of a production of a stochastic nature means that the level of production of a unit of production is limited superiorly by a stochastic frontier, which can be modeled as in Equation 1:

$$Y = f(x) + \varepsilon, \varepsilon = v - u \quad (1)$$

Where the error term is composed of two parts; a random perturbation ***v***, symmetric that is assumed to be identically and independently distributed with mean 0, and *u* is a non-negative error term, which is distributed independently of **v,** following a one-tailed distribution[22]. The random component represents events that are not controllable by the CPU (climatic, social, economic, and political phenomena), while **u** collects the distance of each company to its stochastic frontier, representing a measure of technical inefficiency[23]. Therefore, the Stochastic Production Frontier (SPF) is described by Equation 2:

$$Y *= f(x) + v \quad (2)$$

For SPFs, the technical efficiency index for enterprise ***i*** can be calculated with Equation 3:

$$TE_i = \frac{Y_i}{f(x)+v_i} \quad (3)$$

The SPF is first proposed in the 1970s of the last century[24,25] where they considered[24] the case in which ***u*** is semi-normally distributed, that is, $u - |N(0, \sigma_u)|$ and ***v*** normally distributed. The implications at the conceptual level of PF being stochastic are very important for the interpretation of inefficiency. As Schmidt[24] says, “the farmer whose harvest is devastated by drought or a storm is unfortunate with our measure, but inefficient with the usual measure”. An important limitation of the first estimates of SPF is that only the average efficiency of the sample was calculated, and it was not possible to obtain a measure of the efficiency of each company. Later developments[26] managed to find a measure of individual efficiency using the conditional distribution of ***u*** in ε. The technical efficiency index for each firm ***i*** is:

$$TE_i = exp[-E(u_i|\varepsilon_1)] \quad (4)$$

The most commonly used measure of TE is the ratio of observed production and the corresponding stochastic production frontier, as in Equation 5:

$$TE_I = \frac{q_i}{exp(x_i^{'}\beta+v_i} = \frac{exp(x_i^{'}\beta+v_i-u_i)}{exp(x_i^{'}\beta+v_i)} = exp(-u_i) \quad (5)$$

This measure of technical efficiency takes a value between zero and one. It measures the output of the *i*-th CPU relative to the output that a fully efficient CPU could produce using the same input vector. The first step in calculating the TE is to estimate the parameters of the stochastic production frontier model:

Estimation of parameters

Because model 9.2 includes random terms; the symmetric error (v_i) and a non-negative random variable (u_i), the selected estimation method includes assumptions about both terms. Each v_i is distributed independently of each u_i and both are uncorrelated with the explanatory variables. Additionally, the noise component v_i is assumed to have properties identical to those of the classical linear regression model. The inefficiency component has similar properties except that it has a non-zero mean ($u_i \geq 0$), so Ordinary Least Squares cannot be used. One solution is to make some distribution assumptions regarding the two error terms and estimate the model using the maximum likelihood (ML) method.

Half-normal model

ML estimators were obtained[24] under the following assumptions: $v_i = iidN(0, \sigma_v^2)$ and $u_i = iidN^+(0, \sigma_u^2)$. This indicates that the v_i are normal random variables distributed independently and identically with means and variances zero and the u_i are semi-normal random variables distributed independently and identically with scale parameter. That is, the probability density function (pdf) of each u_i is a truncated version of a normal random variable that has zero mean and variance σ_u^2.

The log-likelihood function was parameterized[24] for this half-normal model in terms of $\sigma^2 = \sigma_v^2 + \sigma_u^2$ and $\lambda^2 = \sigma_u^2/\sigma_v^2 \geq 0$. If $\lambda = 0$, there are no technical inefficiency effects and all deviations from the frontier are due to noise. Using this parameterization, the maximum likelihood function is represented in Equation 6:

$$\text{In}\, L(y|\beta, \sigma, \lambda) = -\frac{1}{2}\text{In}\left(\frac{\pi\sigma^2}{2}\right) + \sum_{i=1}^{1} \text{In}\Phi\left(-\frac{\varepsilon_i\lambda}{\sigma}\right) - \frac{1}{2\sigma^2}\sum_{i=1}^{1} \varepsilon_i^2 \quad (6)$$

Where, y is an output vector; $\varepsilon_i \equiv v_i - u_i \equiv \text{In}\, q_i - x_i^{'}\beta$ is the compound error term; and $\Phi(x)$ is a cumulative distribution function (cfd) of the standard normal random variable evaluated at *x*.

The empirical analysis is based on the estimation of a Cobb-Douglas production function in which both output and inputs are expressed in logarithmic form (Equation 7), so that the estimated coefficients are interpreted as elasticities[27].

$$Ln(Y_i)=\beta_0+\beta_1 Ln(ARE)+\beta_2 Ln(LA)+\beta_3 Ln(ASS)+\beta_4 Ln(HEA)+\beta_5 Ln(FEED)+\varepsilon \qquad (7)$$

In this model, the dependent variable (Yi) is the value of cattle production of the CPUs. The explanatory variables are;

ARECAT is the area for cattle, in hectares owned by the BPU.

LA is the cost of the labor used in production.

ASS is the value of assets; value of machinery, equipment, and production facilities used in the cattle activity.

HEA is the expenditures in health; veterinary supplies and services.

FEED is the cost of feeding; cost of meadow maintenance and supplementary feeding.

Model of individual efficiencies

The estimated model of individual efficiencies (Equation 7) considers the measures of inefficiency estimated in the first stage as a dependent variable. Explanatory variables are a set of variables that hypothetically affect the performance of the CPU[6]. The literature reports as the most common explanatory variables the age of the head of the CPU, they level of schooling, experience in the activity under study, characteristics of the CPU, administration, and environmental factors, among the most cited[28-31]. The multiple regression model was that described in Equation 8:

$$U_i=\delta_0+\delta_1 Ln(Age)+\delta_2 Ln(Schoo)+\delta_3 Ln(Exper)+\delta_4 Ln(Admon)+\delta_5 Ln(TA)+\vartheta_i \qquad (8)$$

Where: Age is the age of the head of the CPU; Schoo is the level of schooling (in years) of the head of the CPU; Exper are the years of experience in the cattle activity; Admon is a dummy variable that takes the value of zero if the CPU does not have an administration system and one if they have an administration system; TA is technical assistance, zero if they did not receive technical assistance and one if they received the service. The variables of the stochastic frontier model and of the individual inefficiency model are showed in Table 2.

Table 2: Variables used in the stochastic frontier production model

Concepts		Frequency	Percentage
Gender of the head	Woman	22	12.0
	Man	162	88.0
Schooling of the head of the CPU	Primary education	69	37.3
	Junior High school	63	34.1
	High school	33	17.8
	Professional	20	10.8
Administration	They do not have a system	114	61.6
	They have a system	71	38.4
Technical assistance	They did not receive	124	67.0
	They did receive	55	33.0
Technological level	Low	94	50.8
	Medium	45	24.3
	High	46	24.9
Strata [number of animal units (A.U.)]	20 or less	89	48.1
	21 to 50	60	32.4
	50 or higher	36	19.5
Variable	**Mean**	**Standard deviation**	
Age of the head	56.0	13.4	
Experience	22.2	13.3	
Animal units	62.5	88.6	
Meadow area, ha	64.9	129.4	
Labor cost, $	37,837	19,354	
Health, $	10,680	3,292	
Feeding costs, $	125,477	72,226	
Assets; annual depreciation, $	35,260	10,500	
Net income, $	83,488	20,824	
Benefit cost (B/C)	1.31	0.26	

Results and discussion

The owners of the BPUs in the Sierra Norte region of Puebla have an average age of 56 yr and range from 25 to 86 yr. The average schooling is 8 years; just under half of producers have completed primary education, 28.6 % finished junior high school and 29.2 % completed high school. The above characteristics are similar to those previously reported(32) for the rural population of the state of Puebla. The experience of producers in the production of cattle was 27 yr, and they have received technical assistance in topics of feeding, animal health and carrying capacity.

Half of the CPUs (50.8 %) are dedicated exclusively to the production of live cattle, 22.2 % are supported by other commercial activities (leases, businesses, and transport), 16.8 % are supported by agricultural and fruit activities (coffee, banana, corn, orange, beans, and vanilla), and 10.3 % report other non-agricultural activities. The percentage of household income generated by non-agricultural productive activities was 55 %, a result similar to that reported in previous studies(33).

The average herd size was 73 heads, with a minimum of 4 and a maximum of 657, which shows a great heterogeneity between the production units, hindering the conditions to compete and achieve a better production process(34). The average area held by the CPUs for grazing was 64 ha and the value of their assets was $135,261 (vehicles, mill, warehouse, milking machine, silo, corral, drinkers, feeder, and scale). The average annual income reported was $83,666, equivalent to 10 % of the herd, for the sale of weaning calves and discarded animals. In the cost structure, feed represented 60 % of the total cost of production, contracted and family labor 18 %, fixed costs and depreciation of assets 17 %, and 5 % was the cost of health.

Results of the econometric model

The results of the stochastic frontier model, using the full sample, are shown in Table 3. The variables had the expected sign, according to economic theory. The positive sign means that increasing the use of the production factor increases production, while the magnitude of the coefficient accounts for the relative importance of each independent variable in explaining the dependent variable.

Table 3: Results of the fit of the stochastic frontier model

Explanatory variable	Coefficient	SE	t-statistic	[95% confidence interval]	
Area of pastures (ARE)	0.025	0.015	1.71*	-0.023	0.073
Labor (LA)	0.263	0.068	3.89**	0.430	0.696
Value of Assets (ASS)	0.365	0.046	7.87**	0.456	0.274
Health (HEA)	0.411	0.081	5.07**	0.152	0.670
Feeding (FEED)	0.195	0.016	11.82**	0.053	0.327
Intercept	-1.777	0.498	-3.57**	-2.753	-0.802
sig2v	-3.481	0.287	-12.13	-4.044	-2.919
sig2u	-2.607	0.369	-7.06	-3.331	-1.884
sigma_v	0.175	0.025		0.132	0.232
sigma_u	0.272	0.050		0.189	0.390
sigma2	0.105	0.021		0.063	0.146
lambda and lambda^2	1.370/1.88	0.072		1.408	1.688
gamma: $\gamma = \sigma_u^2/\sigma_s^2$	0.74				

SE= standard error; * and** significant at 10 % and 5 % respectively.

The variables LA, ASS, HEA, and FEED are significant at 5 %. Area for cattle (ARECAT) was also found significant[30] when studying factors influencing technical efficiency in southeastern Kenya in 2013; a 10 % increase in area for cattle resulted in a 29 % increase in cattle production. The LA variable was found to be significant by several authors[31,35,36]. In a study in Botswana[36] conducted with four strata of producers, they found that increasing the amount of labor by 10 % increases producers' profits by 15 % and 18 %, respectively. The ASS variable has not been identified as significant in the studies reviewed. In the present study, ASS has a positive effect on the production of cattle PUs, as expected by economic theory[20]. The variables HEA and FEED were also reported as significant[14,30,31].

Regarding the fit of the model (7), the estimated stochastic production frontier showed a normal distribution of residuals (Shapiro-Wilks test), no serial correlation of errors (Durbin-Watson), no heteroscedasticity of variance and no autocorrelation or multicollinearity problems. In the values obtained from the general fitted model (Table 3), it was determined that cattle production presents increasing returns to scale (the sum of the coefficients is greater than the unit). To confirm this result, the test was performed for returns to scale, where a value of P= 0.03 < 0.05 was obtained, this causes the existence of constant returns to scale to be rejected[6].

Regarding the inefficiencies of model 8, it was observed that the variance parameters of the maximum likelihood (ML) function are estimated from the total variance model defined as: $\sigma_s^2 = \sigma_v^2 + \sigma_u^2$ and the estimated value in the model for the total variance (σ_s^2) was 0.105. While the lambda value (%) resulted in 1.370, which shows that the variance of the efficiencies is greater than the variance of the random perturbations at 88 % ($\lambda^2 - 1$) and the gamma value obtained from the relationship between the variances $\gamma = \sigma_u^2/\sigma_s^2$ states that 73.9 % of the total variance is explained by the variance of the inefficiencies.

The results of the stochastic frontier model for each stratum of cattle producers are shown in Table 4. Similar to the general model, the models for each estimated stratum showed normal distribution of residuals, no serial correlation of errors, no heteroscedasticity of variance, and no autocorrelation. The variables ARECAT, LA, ASS, HEA, and FEED are significant at 5 % in strata two and three.

Table 4: Results of the Stochastic Frontier model for the strata of CPU

	Stratum 1		**Stratum 2**		**Stratum 3**	
Variable	**Coefficient**	**Z-value**	**Coefficient**	**Z-value**	**Coefficient**	**Z-value**
ARE	0.094	1.85	0.027	2.27	0.073	3.31
LA	0.121	1.76	0.086	2.17	0.163	4.55
ASS	0.116	3.33	0.204	3.83	0.210	4.33
HEA	0.118	2.18	0.158	3.55	0.194	8.95
FEED	0.654	13.64	0.607	14.07	0.670	2.35
Constant	0.641	1.08	0.752	1.59	-1.267	-2.96
/lnsig^{2}v	-3.704	-24.7	-4.206	-23.02	-37.972	-0.06
/lnsig^{2}u	-13.129	-0.07	-13.419	-0.07	-2.339	-9.92
sigma_v	0.157		0.122		0.000	
sigma_u	0.001		0.001		0.310	
sigma^2	0.025		0.015		0.096	
lambda	0.009		0.010		5.460	

In stratum 1, only HEA and FEED were significant. One possible explanation is that small producers have lower quality pastures, without agronomic management, use family labor, little specialized, and the value of their assets is very low, reflecting low-technified CPUs. The feed variable is the one that has the greatest weight in explaining the production of the CPUs for the three strata. The value of assets has twice as much relative weight in strata two and three than in strata one, which means that these CPUs not only have greater investment in assets, but that it is modern and generates greater productivity. The models for strata 2 and 3 show increasing returns to scale, but not the model of stratum 1 which has decreasing returns to scale. In this regard(37), in a study in the United States of America, it was found that as the size of the CPU increases, TE increases, which showed evidence of economies of scale. A possible explanation for the result of stratum 1 is that small producers have a low level of capitalization, low-skilled labor, and since they have little pasture area, they make intensive use, overexploiting the resource(38,39).

Frequency distribution of technical efficiency(TE) by UPG stratum

The TE range for cattle producers was between 0.50 and 0.95. Of the total of the 185 CPUs, 29 % have values between 0.50 and 0.70, 63 % between 0.71 and 0.90, and only 8 % TE values greater than 0.90. Table 5 shows that stratum 3 presents most of the values of 0.91 or more. In this regard(40), it was found that the CPUs with the largest number of animal units and the largest area for cattle presented the highest values of technical efficiency.

Table 5: Frequency distribution (percentages) of technical efficiency (TE) by CPU strata

Strata (no. of heads)	TE (0.50 - 0.70)	TE (0.71-0.90)	TE (> 0.91)	Average
Stratum 1 (20 or less)	47.2	22.2	13.3	0.712
Stratum 2 (21 to 50)	41.5	33.3	0.0	0.751
Stratum 3 (greater than 50)	11.3	44.4	86.7	0.844
General	100.0	100.0	100.0	0.789

Results of individual inefficiencies

Table 6 shows the results of the individual inefficiencies model according to Equation (8). The significant variables, at different levels of significance, and with a negative coefficient, were Schoo, Exper, Admon and TA. The negative sign of the coefficients indicates an inverse relationship between the value of the explanatory variable and the value of the inefficiency. In this regard, previous studies(28,30,36) have reported results that support the results of this study. It was found that more years of schooling reduces inefficiency in values very similar to those reported in this research. Similarly, in the case of the Admon(6,14,41) variable, they found an inverse relationship between having an administration system and inefficiency. For TA(28,30,41), they reported that receiving this service contributes to reducing the inefficiency of the CPUs. In the present study, Age is not significant, a result supported by what was found in the literature(30).

Table 6: General explanatory model of inefficiency

Explanatory variable	Coefficient	Standard error	t-value	Interval
Age (age)	0.02	0.0212	1.1	-0.042 – 0.042
Schooling (Schoo)	-0.23	0.0635	3.6	0.010 – 0.635
Experience (Exper)	-0.12	0.0739	1.7	-0.012 – 0.024
Administration (Admon)	-0.23	0.0824	2.5	-0.001 - 0.048
Technical Assistance (TA)	-0.22	0.0136	14.9	0.176 - 0.230
Constant	-0.47	0.799	-0.6	-0.626 – (-0.310)
Fit (R2)/R2 adjusted		0.7929 / 0.7859		
Heteroscedasticity(Cook-Weisberg)		Prob> Ji^2=0.000		
Normality: (Shapiro-Wilk)		0.00002		
Inflation factor variance		1.59		

The above results suggest that reducing inefficiency should be addressed by providing public technical assistance services, an activity that, in Mexico, has been at very low levels since the nineties. In this regard, in a study on the use of livestock innovations in Sinaloa(7), it was reported that only 3 % of the PUs receive technical assistance services, and of these, the CPUs represent only 19.3 %. Training in the management of the CPU, including administrative services, should also be a central aspect, in addition to the technological issues of cattle farming.

Results of the technical inefficiency model by CPU strata

Table 7 reports the results of the model of technical inefficiency by strata of CPUs. For stratum 1, Age and Exper are significant, but not Schoo, Admon and TA. The producers of this stratum have low schooling, 6 years on average, have experience, and most do not have administration systems and do not receive any type of technical assistance services. For stratum 2, Schoo, Exper and TA are significant. It was observed that the years of schooling increase significantly for the producers of this stratum. Finally, for stratum 3, four variables are significant. It should be noted that the values of the coefficients are in the range of 0.13 to 0.28, which shows an important effect of these variables to reduce inefficiency. Therefore, improving administration systems and the quality of technical assistance are aspects that can lead these CPUs to be highly efficient(14,30,41).

Table 7: Results of the technical inefficiency model by CPU strata

	Stratum 1			Stratum 2			Stratum 3		
Variable	**Coef.**	**t**	**SE**	**Coef.**	**t**	**SE**	**Coef.**	**t**	**SE**
Age	-0.066	-2.15*	0.031	0.017	0.42	0.041	0.065	1.38	0.047
Schoo	-0.001	-0.03	0.007	-0.184	-2.08*	0.088	-0.142	-2.59*	0.055
Exper	-0.027	-2.30*	0.012	-0.126	-2.09*	0.060	-0.197	-4.28*	0.046
Admon	0.033	1.63	0.020	0.017	0.81	0.020	-0.281	-5.73*	0.049
TA	0.108	1.42	0.076	-0.150	-7.34*	0.020	-0.134	-5.56*	0.024
Constant	-0.238	-2.10	0.113	-0.481	-2.97	0.162	-0.700	-3.89*	0.179
R2/R2 Adj.	0.7935 / 0.7884			0.8027 / 0.7904			0.8214 / 0.7945		
D-W	0.0719			0.0005			0.0247		
Normality	0.01219			0.69848			0.17108		
VIF	1.4			1.23			1.7		

SE= standard error; D-W= Durbin-Watson; VIF= variance inflation factor.

Conclusions and implications

The production of live cattle in the study region is carried out with a high degree of efficiency, however, there is significant room for improvement, especially in small producers. The most efficient producers have more schooling, receive technical assistance services, use administration systems, have more pasture area, more heads and use better animal health systems. Labor, health, food, and asset costs can be reduced while maintaining the same level of production. Small producers, which are the largest subsector in number, can improve their production by attending to food and health aspects, with the other variables constant. The use of technical assistance services reduces inefficiency, through a more intensive and appropriate use of available livestock technology. Due to the above, it is advisable to make these services extensive and permanent to all farmers, especially small farmers. The positive relationship between herd size and productive efficiency may be related to the benefits of economies of scale, in the case of medium and large producers, so financing to increase the herd can generate production and efficiency gains.

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